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COOPERATIVE INTERNATIONAL PROGRAM ON MECHANICAL STRENGTH MEASUREMENTS OF CERAMICS*

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Research conducted on structural ceramic characterization as part of an IEA Annex II Agreement between the United States, the Federal Republic of Germany, and Sweden, showed that high reliability measurements of critical mechanical properties such as the strength and statistical estimators for the strength distribution is very difficult to achieve, and that present methods provide property values with large uncertainties. All measurements in this earlier phase were room temperature flexural strength. The critical properties include, (a) determination of the probability distribution function which best describes the fracture strength, (b) determination of the two Weibull parameters α and β which describe this distribution function, and (c) the average, either for the Gaussian or Weibull distribution functions. This research was concluded in 1989, with the publication of three reports. Representatives of the member countries proposed that follow-on research, as Subtask 5 of the agreement, be conducted to provide data which could be used as preliminary information for the development of standardized flexure strength measurement techniques having much higher confidence levels than presently available methods. In addition, strong interest had developed in methods for measuring the tensile strength of structural ceramics, and this type of research was also included in the plan for follow-on research. Finally, interest had also developed in multiaxial strength measurement methods and the relationship between the strength values from multiaxial methods and those from flexural and uniaxial tensile methods. Therefore, these types of measurements were also included in the new planned research. Importantly, representatives of Japan participated in early discussions of the content of this new research, and Japan is a participant in Subtask 5.

The four member countries have each developed a research plan which has been agreed to by the other members. Only a brief description of the research plans and status will be given here. Each country has selected a silicon nitride which is commercially available and is providing specimens of the material to laboratories in

each country. In Germany, four point flexure, uniaxial tensile strength and four other strength measurement methods are being studied in 15 participating laboratories. In Sweden, four point flexure, uniaxial tensile strength and two multiaxial strength measurement methods are being studied in four participating laboratories. In Japan, four point flexure strength measurements at both room temperature and 1250 C, plus uniaxial tensile strength measurements using three different specimen geometries. in six participating laboratories. In the United States, four point flexure strength measurements at both room temperature and 1250 C, plus uniaxial tensile strength measurements at room temperature are being made in ten participating laboratories. In all countries, 100% fractography is being employed. In addition, extensive use of strain gage techniques is being utilized to provide data regarding the exact strain conditions developed in the specimens during loading to fracture.

This research, as currently planned, includes a total of 2000 flexure strength specimens, 430 tensile strength specimens, and 280 multiaxial strength specimens for a grand total of 2710 including exchange specimens. Extensive specimen exchange is an important part of this research to determine how measured strength and other values compare for a given material when measured in different laboratories in different countries. A total of 1050 specimens are being exchanged by the member countries.

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DISCLAIMER

COOPERATIVE INTERNATIONAL PROGRAM ON MECHANICAL STRENGTH MEASUREMENTS OF CERAMICS

AUTOMOTIVE TECHNOLOGY DEVELOPMENT
CONTRACTORS' COORDINATION MEETING

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HIGH TEMPERATURE MATERIALS LABORATORY
OAK RIDGE NATIONAL LABORATORY

OCTOBER 24, 1990
DEARBORN, MI

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IEA ANNEX II SUBTASK 4 RESEARCH ON CERAMIC MECHANICAL PROPERTIES WAS SUCCESSFULLY COMPLETED

- TOTAL OF 21 LABORATORIES IN THREE COUNTRIES
- TOTAL OF 2597 FLEXURE SPECIMENS WERE STUDIED
- ALL MEASUREMENTS WERE AT ROOM TEMPERATURE
- THREE STRUCTURAL CERAMICS WERE STUDIED BY ALL LABS
  - GTE/WESGO SILICON NITRIDE (UNITED STATES)
  - ESK SILICON CARBIDE (FEDERAL REPUBLIC OF GERMANY)
  - ASEA CERAMA SILICON NITRIDE (SWEDEN)
- FRACTOGRAPHY PERFORMED ONLY ON SELECTED SPECIMENS

THREE REPORTS DESCRIBING THE RESEARCH HAVE BEEN PUBLISHED

- "FRACTOGRAPHY ANALYSIS OF SILICON NITRIDE AND SILICON CARBIDE STRUCTURAL CERAMICS," ORNL, JUNE 1989

- "STATISTICAL ANALYSIS OF FLEXURE STRENGTH DATA," UNIV. OF KARLSRUHE, JUNE 1989

- "ANALYSIS OF ERROR SOURCES IN FOUR POINT FLEXURE STRENGTH MEASUREMENTS OF STRUCTURAL CERAMICS," UNIV. OF KARLSRUHE, DECEMBER 1989

THERE WERE FIVE CONCLUSIONS FROM THIS RESEARCH

- WEIBULL PARAMETER α VARIED FROM 40 TO 70%
  - IN SPITE OF 60 TO 80 SPECIMEN DATA SETS
  - IN SPITE OF CAREFUL RANDOMIZING OF SPECIMENS
  - IN SPITE OF USE OF STANDARDIZED FIXTURES IN SOME COUNTRIES FOR ALL PARTICIPANTS

- WEIBULL PARAMETER β VARIED FROM 15 TO 18%

- KOLMOGOROV-SMIRNOV STATISTIC WAS POTENTIALLY USEFUL DEVICE FOR DECIDING IF DATA SETS BELONGED TO THE SAME PROBABILITY DENSITY FUNCTION

- KRUSKALL-WALLACE METHODS WERE LATER IDENTIFIED AS MORE ACCEPTABLE FOR THIS PURPOSE

- DEVELOPMENT OF STANDARD METHODS FOR FLEXURE STRENGTH MEASUREMENTS TO ACHIEVE HIGH LEVEL OF CERTAINTY FOR σ (AVG.), α , AND β WILL REQUIRE DETAILED UNDERSTANDING OF STRESS DISTRIBUTIONS WITHIN A SPECIMEN IN A "STANDARDIZED" FIXTURE

SUMMARY OF PROPOSED RESEARCH

IEA ANNEX II, SUBTASK 5

THE UNITED STATES, GERMANY, SWEDEN, AND JAPAN

GERMAN RESEARCH PLAN, SUBTASK 5

- FOUR POINT FLEXURE STRENGTH AT ROOM TEMP.
  - 200 SPECIMENS FRACTURED, ESK SILICON NITRIDE
  - EXCHANGE 30 SPECIMENS WITH THE U.S.
  - EXCHANGE 50 SPECIMENS WITH JAPAN
  - EXCHANGE 200 SPECIMENS WITH SWEDEN

- UNIAXIAL TENSILE STRENGTH
  - 20 BUTTONHEAD SPECIMENS, 30 ASCERA, ESK SILICON NITRIDE
  - EXCHANGE 10 BUTTONHEAD AND 30 ASCERA SPECIMENS WITH SWEDEN
  - EXCHANGE 5 BUTTONHEAD SPECIMENS WITH THE U.S.
  - EXCHANGE 5 BUTTONHEAD SPECIMENS WITH JAPAN

- CONCENTRIC RING-ON-RING BIAXIAL STRENGTH
  - 30 SPECIMENS, ESK SILICON NITRIDE
  - 30 SPECIMENS FROM SWEDEN

- BALL-ON-RING BIAXIAL STRENGTH
  - 30 SPECIMENS FROM SWEDEN

- DIAMETRAL COMPRESSION (BRAZILIAN DISK)
  - 30 SPECIMENS, ESK SILICON NITRIDE
  - 30 SPECIMENS FROM SWEDEN

- SPIN DISK
  - TOTAL OF 10 SPECIMENS, ESK SILICON NITRIDE
  - EXCHANGE 10 SPECIMENS WITH SWEDEN

- COMPRESSIVE STRENGTH
  - TOTAL OF 30 SPECIMENS, ESK SILICON NITRIDE
  - 30 SPECIMENS FROM SWEDEN

- 100% FRACTOGRAPHY

SWEDISH RESEARCH PLAN, SUBTASK 5

- FOUR POINT FLEXURE STRENGTH AT ROOM TEMP.
  - 200 SPECIMENS FRACTURED, ASCERA SILICON NITRIDE
  - EXCHANGE 30 SPECIMENS WITH THE U.S.
  - EXCHANGE 50 SPECIMENS WITH JAPAN
  - EXCHANGE 200 SPECIMENS WITH GERMANY

- UNIAXIAL TENSILE STRENGTH
  - 10 ESK BUTTONHEAD SPECIMENS, 30 ASCERA, ASCERA SILICON NITRIDE
  - EXCHANGE 10 BUTTONHEAD AND 30 ASCERA SPECIMENS WITH GERMANY
  - EXCHANGE 5 BUTTONHEAD SPECIMENS WITH THE U.S.
  - EXCHANGE 5 BUTTONHEAD SPECIMENS WITH JAPAN

- BALL-ON-RING BIAXIAL STRENGTH
  - 30 SPECIMENS, ASCERA SILICON NITRIDE
  - 30 SPECIMENS FROM GERMANY

- SPIN DISK
  - TOTAL OF 10 SPECIMENS, ASCERA SILICON NITRIDE
  - EXCHANGE 10 SPECIMENS WITH GERMANY

- 100% FRACTOGRAPHY

JAPANESE RESEARCH PLAN, SUBTASK 5

- FOUR POINT FLEXURE STRENGTH AT ROOM TEMP.
  - 240 JIS AND 10 NON JIS SPECIMENS FRACTURED, KYOCERA SILICON NITRIDE
  - EXCHANGE 30 SPECIMENS WITH THE U.S.
  - EXCHANGE 50 SPECIMENS WITH GERMANY AND SWEDEN
- FOUR POINT FLEXURE STRENGTH AT 1250 °C, KYOCERA SILICON NITRIDE
  - 120 JIS SPECIMENS FRACTURED
- UNIAXIAL TENSILE STRENGTH
  - 20 BUTTONHEAD SPECIMENS, KYOCERA SILICON NITRIDE
  - 20 JIS 1606 TENSILE SPECIMENS, KYOCERA SILICON NITRIDE
  - 20 GIRIN TENSILE SPECIMENS, KYOCERA SILICON NITRIDE
  - EXCHANGE 5 BUTTONHEAD SPECIMENS WITH THE U.S., GERMANY, AND SWEDEN
- 100% FRACTOGRAPHY

UNITED STATES RESEARCH PLAN, SUBTASK 5

- FOUR POINT FLEXURE STRENGTH AT ROOM TEMP.
  - 300 SPECIMENS FRACTURED, 10 LABORATORIES, GARRETT GN-10 SILICON NITRIDE
  - STRAIN GAGED CALIBRATION SPECIMENS
  - EXCHANGE 30 SPECIMENS WITH GERMANY, SWEDEN, AND JAPAN
- FOUR POINT FLEXURE STRENGTH AT 1250 °C, GARRETT GN-10 SILICON NITRIDE
  - 150 SPECIMENS FRACTURED , 10 LABORATORIES
  - STRAIN GAGED CALIBRATION SPECIMENS
- UNIAXIAL TENSILE STRENGTH
  - 150 BUTTONHEAD GEOMETRY FRACTURED, GARRETT GN-10 SILICON NITRIDE
  - 10 LABORATORIES
  - EXCHANGE 5 BUTTONHEAD SPECIMENS WITH GERMANY, SWEDEN , AND JAPAN
- 100% FRACTOGRAPHY

GERMANY, SUBTASK 5
SUMMARY OF TEST TECHNIQUES AND MATERIALS

- MATERIAL STUDIED IS ESK HIP-SILICON NITRIDE
  - SCHOTT GLASS CERAMIC USED AS REFERENCE
  - ESK MATERIAL PROVIDED TO SWEDEN FOR JOINT RESEARCH
- ALL SPECIMENS FABRICATED FROM SAME PRODUCTION CYCLE
- SPECIMEN MACHINING CONDUCTED BY SINGLE LABORATORY
- EACH TEST TYPE PERFORMED BY ONE OR TWO LABORATORIES HAVING EXPERTISE IN PARTICULAR AREA
- ALL SPECIMENS EXAMINED FRACTOGRAPHICALLY TO LOCATE CRITICAL DEFECTS
- ADVANCED STATISTICAL TREATMENTS USED TO COMPARE DATA
  - EXAMINE EFFECTS OF MULTIAXIAL STRESS STATES AND BIMODAL FLAW DISTRIBUTIONS (SURFACE VERSUS VOLUME FLAWS)

GERMANY, SUBTASK 5 PARTICIPANTS

- CFI, RÖDENTAL
  - FOUR POINT BEND TEST
- FHI, FREIBURG
  - RING-ON-RING AND BUTTON-HEAD TESTS
  - EVALUATION OF FRACTOGRAPHIC ANALYSIS
- MPI, STUTTGART
  - ASCERA TENSILE TEST
- UNIVERSITY OF KARLSRUHE
  - BRAZILIAN AND COMPRESSION
  - STATISTICAL EVALUATION
- RWTH, AACHEN
  - BRAZILIAN AND COMPRESSION TESTS
- DAIMLER-BENZ
  - DISK SPIN TESTS
- PLUS HOECHST CERAMTEC, DIDIER, FELDMÜHLE, DEGUSSA, LONZA, R. BOSCH, SIGRI, ISD ELEKTROKERAMIK, MAN TECHNOLOGIE

SWEDEN, SUBTASK 5
SUMMARY OF TEST PROCEDURES

- ROOM TEMPERATURE FOUR-POINT FLEXURE MEASUREMENTS
  - DATA COMPARED WITH ASCERA HYDRAULIC TENSILE TESTS
- CONCENTRIC BALL-ON-RING MEASUREMENTS
  - TECHNIQUE EXCLUDES EDGE EFFECTS
- UNIAXIAL TENSILE STRENGTH MEASUREMENTS
  - ASCERA HYDRAULIC TENSILE GEOMETRY
  - FIVE GN-10 SILICON NITRIDE BUTTON-HEAD TENSILE SAMPLES PROVIDED BY UNITED STATES
- DISK SPIN STRENGTH MEASUREMENTS

SWEDEN, SUBTASK 5
SUMMARY OF TEST TECHNIQUES AND MATERIALS

- HIP-SILICON NITRIDE (ABB CERAMA) USED FOR ALL TESTING
  - MATERIAL PROVIDED TO GERMANY FOR JOINT EFFORT
- ALL SPECIMENS FABRICATED FROM SAME PRODUCTION CYCLE
- SPECIMEN MACHINING CONDUCTED BY SINGLE LABORATORY
- X-RAY MICRORADIOGRAPHY AND X-RAY RESIDUAL STRESS ANALYSIS USED TO CHARACTERIZE TEST SPECIMENS
  - TECHNIQUES APPLIED TO INDENTED FRACTURE TOUGHNESS SPECIMENS
- ALL SPECIMENS EXAMINED FRACTOGRAPHICALLY TO LOCATE CRITICAL DEFECT
- ADVANCED STATISTICAL TREATMENTS USED TO COMPARE DATA
  - EXAMINE EFFECTS OF MULTIAXIAL STRESS STATES AND BIMODAL FLAW DISTRIBUTIONS (SURFACE VERSUS VOLUME FLAWS)

SWEDEN, SUBTASK 5 PARTICIPANTS

- SWEDISH CERAMIC INSTITUTE
  - ASCERA TENSILE STRENGTH
  - FOUR-POINT FLEXURE STRENGTH
  - BALL-ON-RING BIAXIAL
- UNITED TURBINE
  - SPIN DISK
- LINKOPING UNIVERSITY
  - X-RAY MICRORADIOGRAPHY AND X-RAY RESIDUAL STRESS
- VOLVO AEROSPACE DIVISION
  - BUTTONHEAD TENSILE TEST (GAGED SPECIMENS)

GERMANY AND SWEDEN RESEARCH, SUBTASK 5 INVOLVES JOINT EFFORTS

- SWEDEN WILL PROVIDE GERMANY WITH HIP-SILICON NITRIDE (ABB CERAMA)
- GERMANY WILL PROVIDE SWEDEN WITH ESK MATERIAL
  - A REFERENCE GLASS CERAMIC USED IN THE GERMAN TESTING
- IDENTICAL MACHINING PROCEDURES BEING USED
- COMMON TESTS WILL INCLUDE ASCERA TENSILE, BIAXIAL RING, BALL-ON-RING, AND SPIN DISK MEASUREMENTS
  - SWEDEN WILL ALSO SUPPLY SPECIMENS FOR THE BRAZILIAN AND COMPRESSIVE STRENGTH MEASUREMENTS IN GERMANY
- 100% FRACTOGRAPHIC ANALYSIS

JAPAN, SUBTASK 5
SUMMARY OF TEST PROCEDURES

- FOUR-POINT FLEXURE STRENGTH ON STRAIN GAGED SPECIMENS AT ROOM TEMPERATURE
  - MOST TESTING IN ACCORDANCE WITH JIS R1601 (3 BY 4 mm CROSS SECTIONS; 30 mm OUTER SPAN; 10 mm INNER SPAN)
  - SOME TESTS CONDUCTED USING U.S. STANDARD
  - EXCHANGE WITH OTHER PARTICIPATING COUNTRIES

- HIGH TEMPERATURE (1250°C) FLEXURE STRENGTH IN ACCORDANCE WITH JIS R1604
  - GAGED SPECIMEN USED TO EVALUATE HIGH TEMPERATURE LOAD TRAIN

- ROOM TEMPERATURE UNIAXIAL TENSILE TESTING ON STRAIN GAGED SPECIMENS
  - FIVE GARRETT GN-10 SILICON NITRIDE TENSILE SAMPLES PROVIDED BY U.S.
  - EXCHANGE WITH OTHER PARTICIPATING COUNTRIES

- 100% FRACTOGRAPHY FOR BOTH FLEXURE AND TENSILE

PROPOSAL FOR SUBTASK 5- JAPAN PARTICIPANTS

- GOVERNMENT RESEARCH INSTITUTE, NAGOYA
- KYOCERA COMPANY, CENTRAL RESEARCH LABORATORY
- NKK COMPANY, ADVANCED TECHNOLOGY RESEARCH CENTER
- NGK INSULATORS, MATERIALS RESEARCH LABORATORY
- NGK SPARK PLUGS, RESEARCH AND DEVELOPMENT CENTER
- JAPAN FINE CERAMICS CENTER

PROPOSAL FOR SUBTASK 5- JAPAN
SUMMARY OF TEST TECHNIQUES AND MATERIALS

- KYOCERA SILICON NITRIDE SELECTED
- SIX PARTICIPATING LABORATORIES
  – BUTTONHEAD TENSILE SPECIMENS ALSO SUPPLIED TO GERMANY, SWEDEN, AND THE UNITED STATES

PROPOSAL FOR SUBTASK 5-UNITED STATES SUMMARY OF TEST PROCEDURES

- ROOM TEMP. FOUR-POINT FLEXURE MEASUREMENTS (TASK 1)
  – FIXTURES IDENTICAL TO THOSE USED IN SUBTASK 4

- GAGED SPECIMEN USED TO EVALUATE ROOM TEMPERATURE LOAD TRAIN (TASK 1)
  – 3 LOAD/UNLOAD CYCLES APPLIED BEFORE AND AFTER 30 SPECIMENS ARE FRACTURED

- GAGED SPECIMEN USED TO EVALUATE HIGH TEMPERATURE LOAD TRAIN (TASK 2)
  – 3 LOAD/UNLOAD CYCLES APPLIED BEFORE 15 SPECIMENS ARE FRACTURED

- HIGH TEMPERATURE (1250°C) FOUR-POINT FLEXURE MEASUREMENTS (TASK 3)

UNITED STATES, SUBTASK 5
SUMMARY OF TEST PROCEDURES-CONTINUED

- ROOM TEMP. TENSILE STRENGTH MEASUREMENTS (TASK 4)
  - BUTTONHEAD TENSILE GEOMETRY UTILIZED
  - BOTH STRAIGHT AND TAPERED COLLET GRIPS ARE EVALUATED
  - STRAIN GAGES APPLIED TO ALL SPECIMENS
  - GAGE OUTPUTS MONITORED WHILE SPECIMEN IS LOADED TO FAILURE

- 15 SPECIMENS MEASURED BY EACH PARTICIPANT
  - 5 STRAIGHT COLLET SPECIMENS AT HTML/ORNL
  - 5 TAPERED COLLET SPECIMENS AT HTML/ORNL
  - 5 STRAIGHT COLLET SPECIMENS AT PARTICIPATING LABORATORY IF FACILITIES ARE AVAILABLE

- 100% FRACTOGRAPHY

UNITED STATES, SUBTASK 5
SUMMARY OF TEST TECHNIQUES AND MATERIALS

- HIP-SILICON NITRIDE (GARRETT GN-10) USED
  - FLEXURE SPECIMEN DIMENSIONS 3 X 4 X 50 mm
  - 30 SPECIMENS AT ROOM TEMPERATURE
  - 15 SPECIMENS AT 1250°C

- FLEXURE SPECIMENS FABRICATED FROM BILLETS PRODUCED DURING SAME PRODUCTION CYCLE
  - ALL FLEXURE SPECIMENS MACHINED BY COMMERCIAL VENDOR (COMPLETED 2/1/1990)

- TENSILE SPECIMENS FABRICATED FROM HIPed RODS PRODUCED DURING SAME PRODUCTION CYCLE
  - ALL ROD SPECIMENS REQUIRED FOR U.S. PARTICIPANTS HAVE BEEN RECEIVED
  - 15 ADDITIONAL SPECIMENS FOR GERMANY, SWEDEN, AND JAPAN WERE RECEIVED IN JULY 1990

UNITED STATES, SUBTASK 5
SUMMARY OF TEST TECHNIQUES AND MATERIALS-CONT.

- ALL TENSILE RODS MACHINED AT ONE FACILITY
  - OPTICAL COMPARATOR USED TO EXAMINE DIMENSIONAL CONSISTENCY
  - SURFACE ROUGHNESS EVALUATED WITH PROFILOMETER
  - ALL STRAIN GAGES APPLIED BY HTML/ORNL STAFF

- ADVANCED STATISTICAL TREATMENTS USED TO COMPARE DATA
  - EFFECT OF LOAD TRAIN VARIATIONS UPON STRENGTH DATA WILL BE EXAMINED IN DETAIL

UNITED STATES, SUBTASK 5 PARTICIPANTS

- ALLISON GAS TURBINE
- CARBORUNDUM COMPANY
- CORNING, INC.
- FORD MOTOR COMPANY
- ALLIED-SIGNAL AEROSPACE COMPANY
- GENERAL ELECTRIC COMPANY
- GTE LABORATORIES
- NASA LEWIS RESEARCH CENTER
- NORTON COMPANY
- ORNL

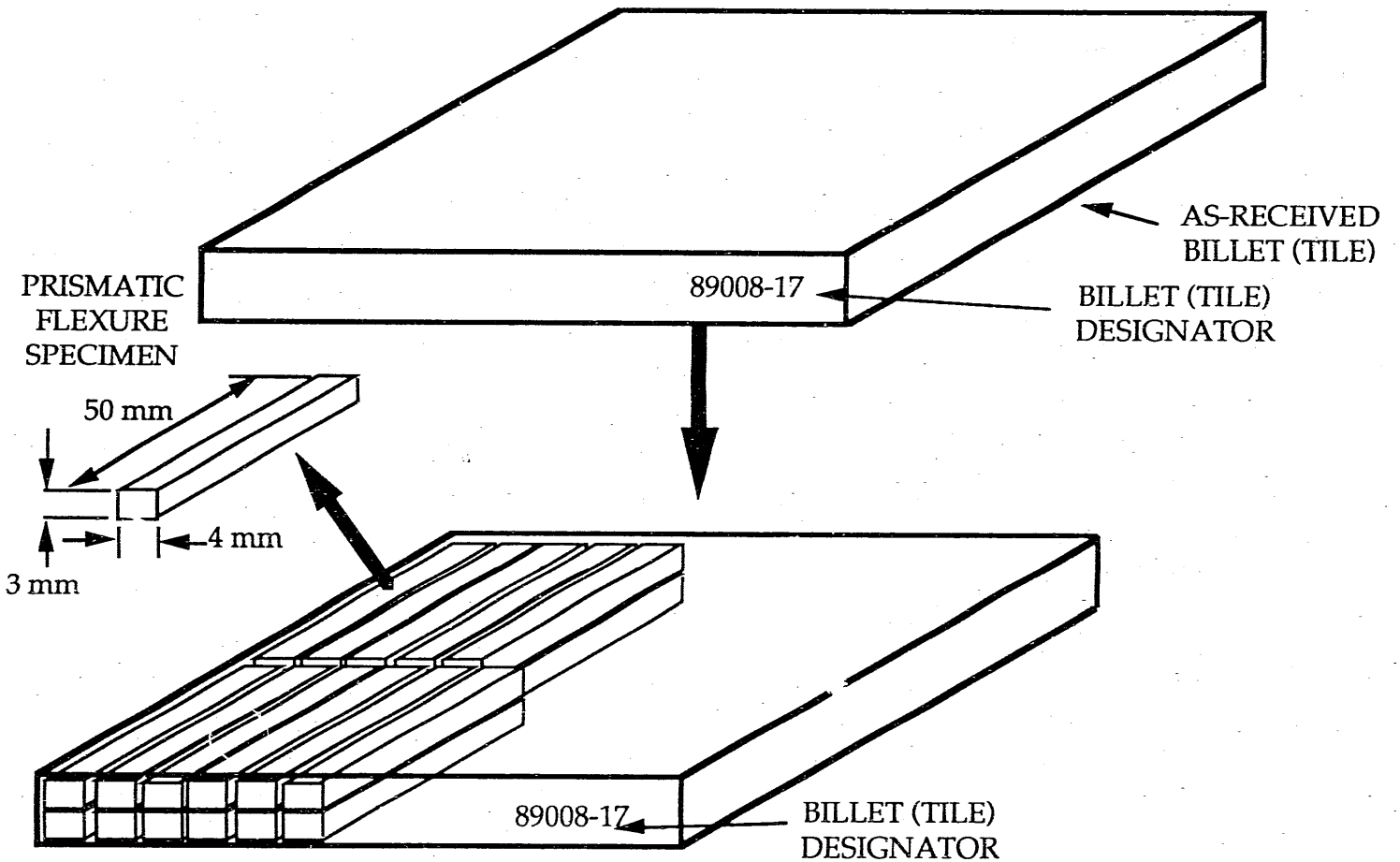
STATUS OF U.S. RESEARCH IN SUBTASK 5

ROOM AND HIGH TEMPERATURE FLEXURE STUDIES ARE NOW COMPLETED

- EXPERIMENTS AT NASA LEWIS RESEARCH CENTER, ALLISON GAS TURBINE, AND FORD MOTOR COMPANY COMPLETED 6/20/90
- EXPERIMENTS AT ALLIED-SIGNAL AEROSPACE COMPANY COMPLETED 6/28/90
- VISITS TO CORNING, INC., GENERAL ELECTRIC COMPANY, GTE LABORATORIES, CARBORUNDUM COMPANY, AND NORTON COMPANY WERE COMPLETED 8/9/90

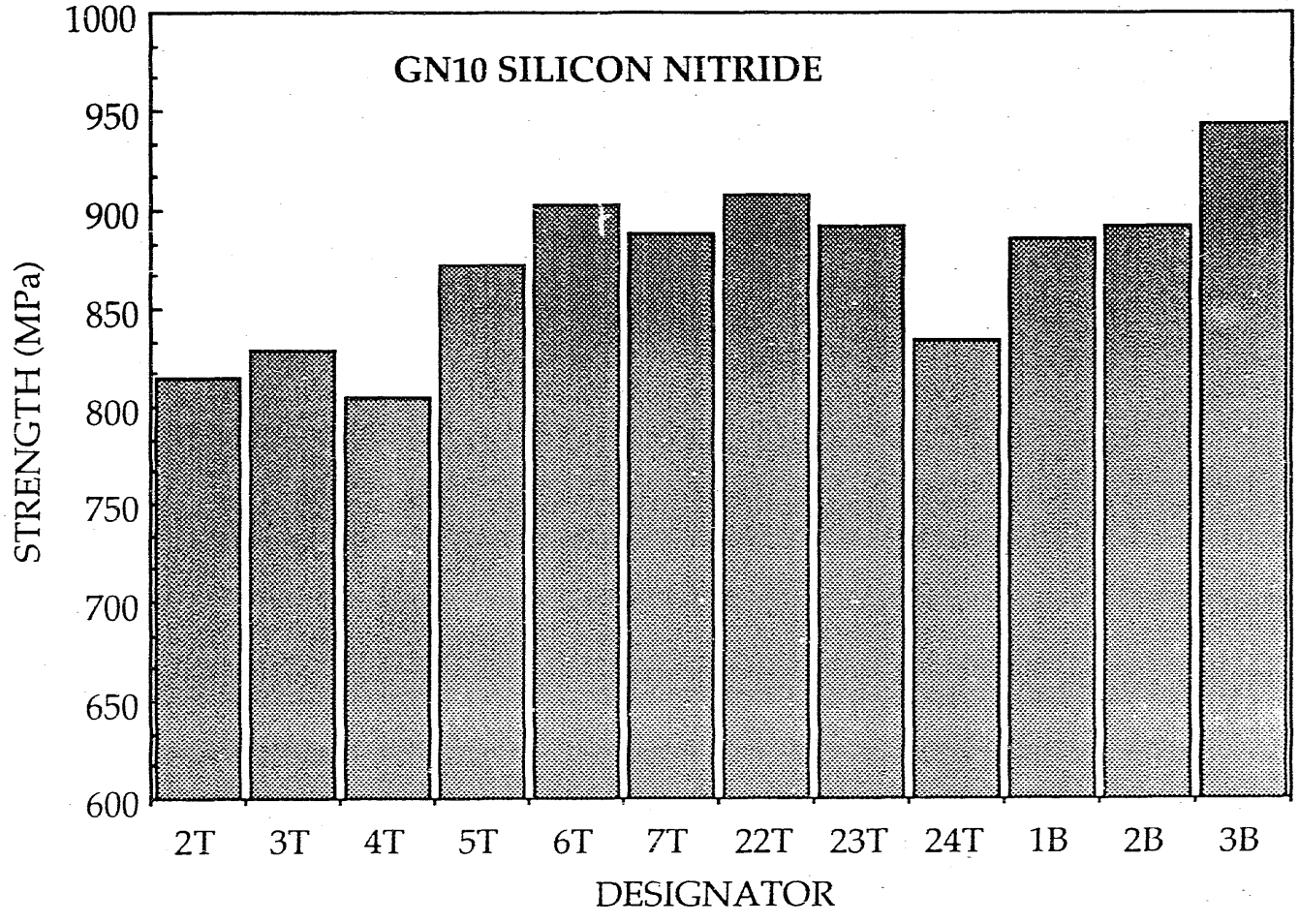
DATA GENERATED INCLUDE ROOM AND HIGH TEMPERATURE FLEXURE STRENGTHS AND STRAIN READINGS ASSOCIATED WITH GAGED SPECIMEN LOADED IN THE ROOM AND HIGH TEMPERATURE FOUR POINT FLEXURE FIXTURES

FLEXURE SPECIMENS WERE MACHINED FROM RECTANGULAR HIPed SILICON NITRIDE GN-10 BILLETS (GARRETT) FABRICATED DURING THE SAME PRODUCTION CYCLE

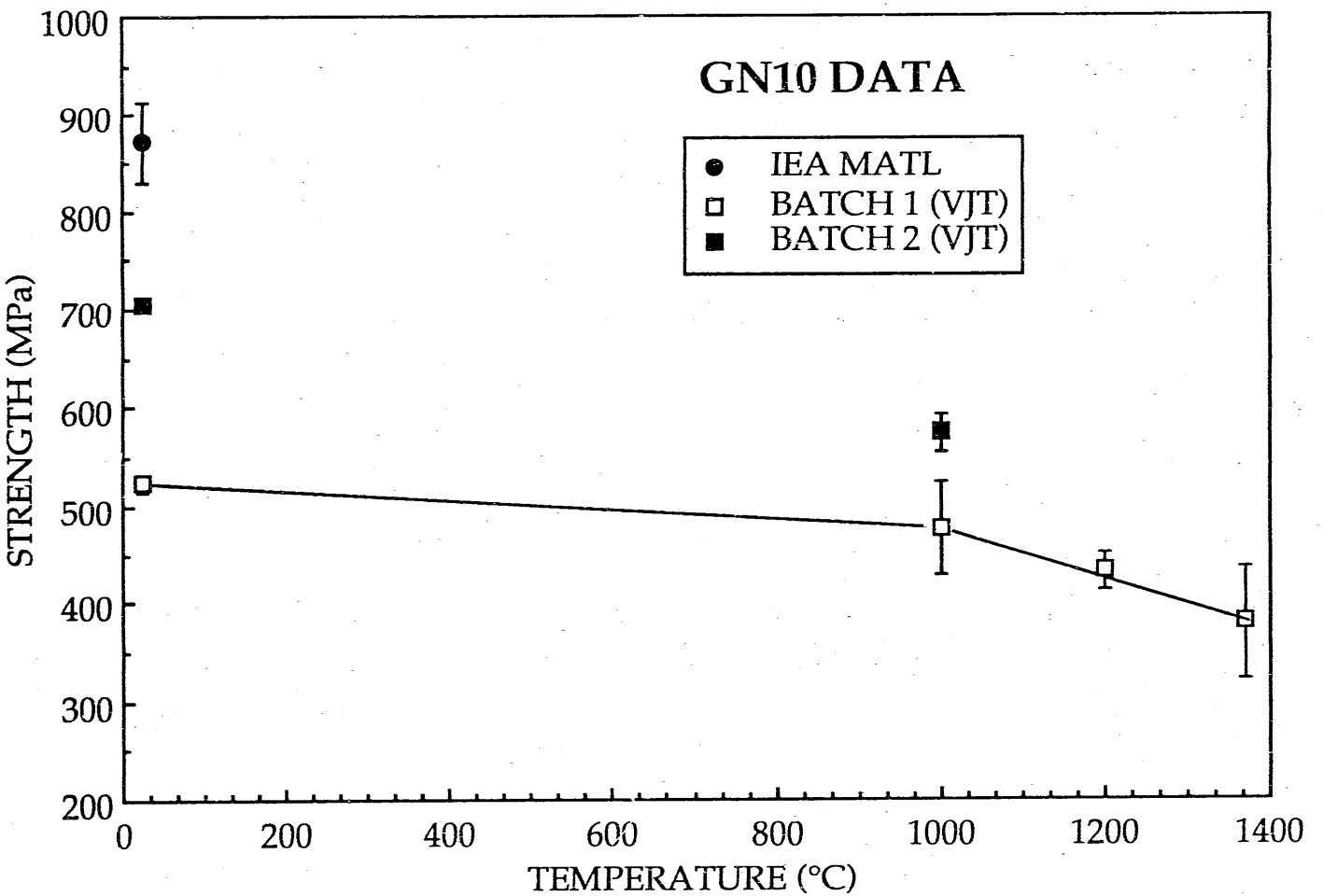


MACHINING PROCEDURE IDENTICAL TO THAT USED IN SUBTASK 4

VARIATIONS OF FLEXURE STRENGTH WITH POSITION IN ORIGINAL BILLET DID NOT APPEAR TO BE SIGNIFICANT

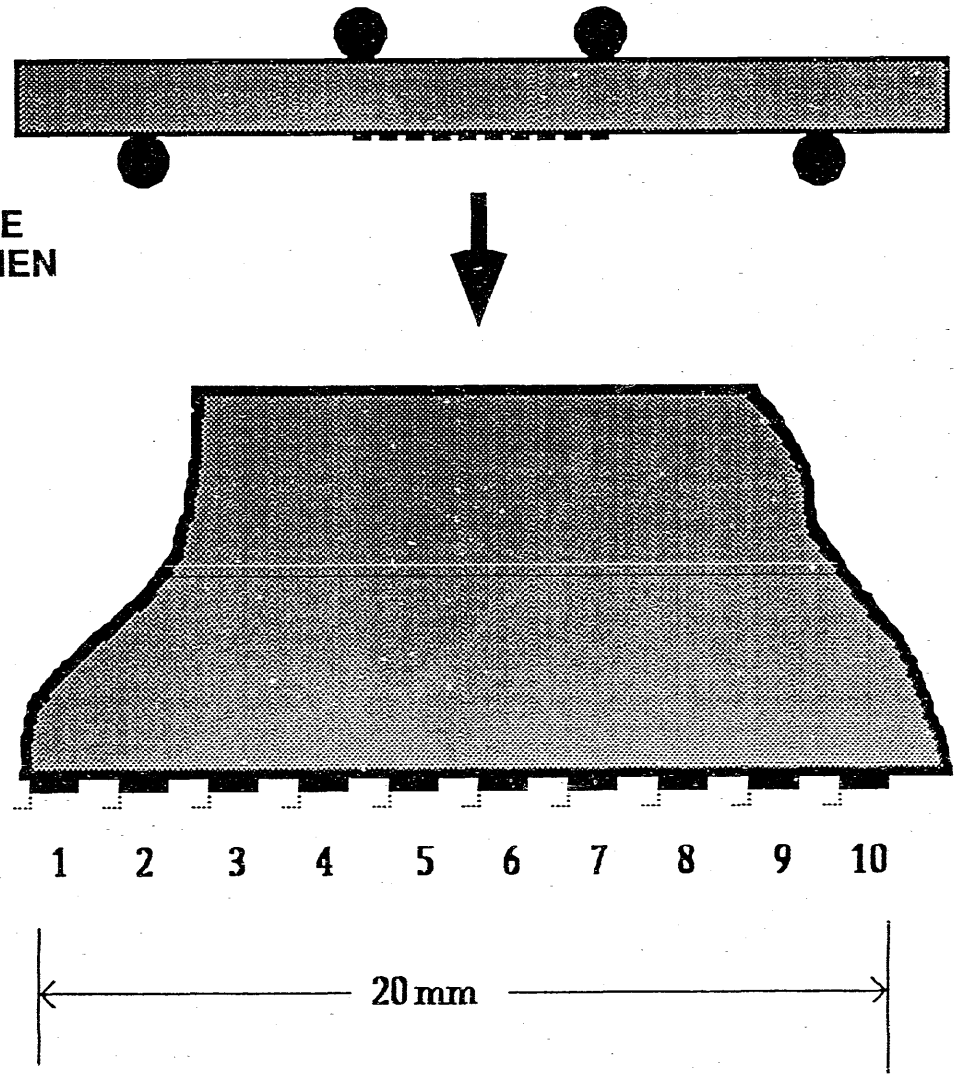


STRENGTH VALUES OF FLEXURE SPECIMENS PREPARED FROM A SINGLE BILLET WERE CONSISTENT WITH OTHER SILICON NITRIDES

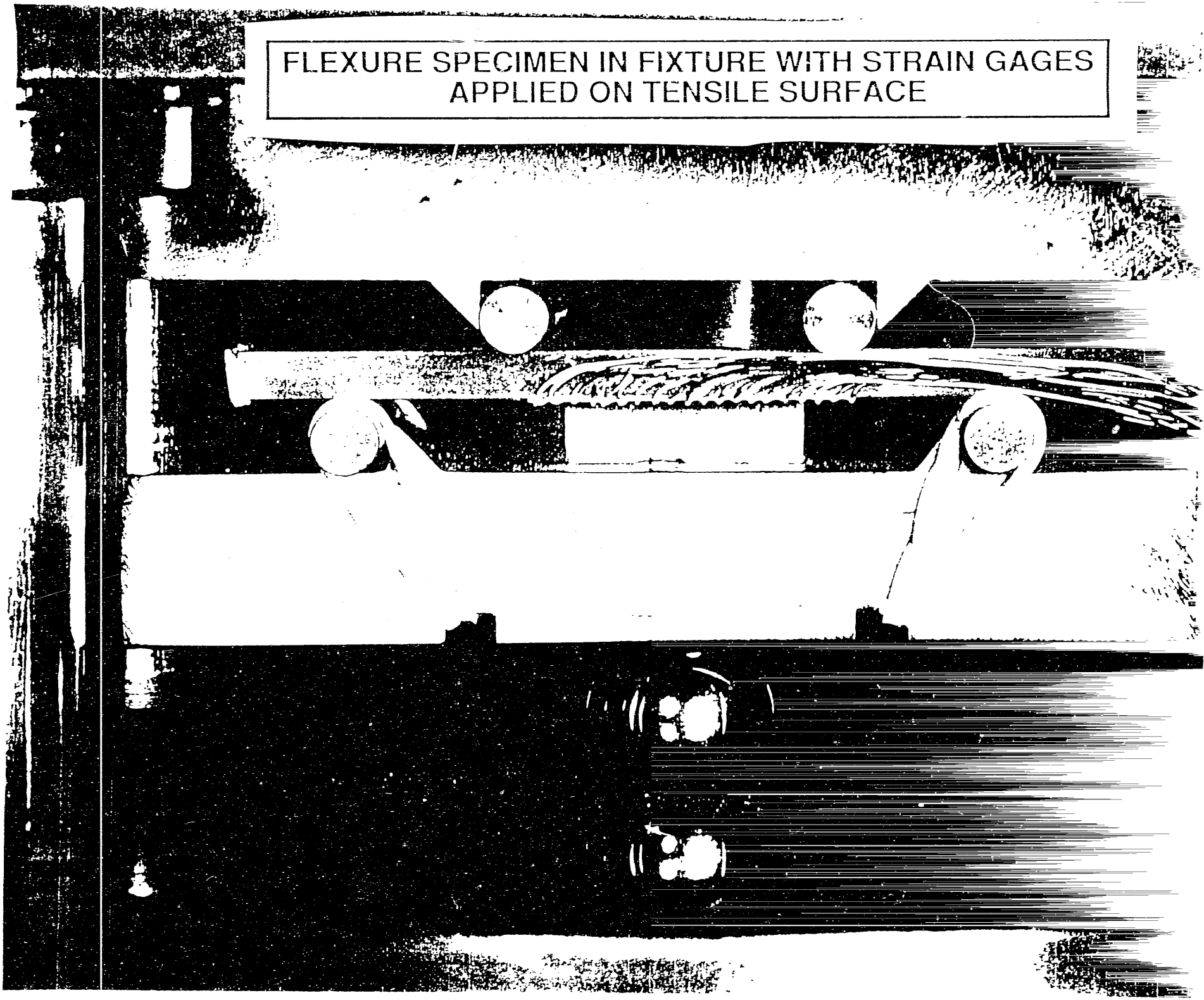


STRAIN GAUGED FLEXURE SPECIMEN WAS USED TO MEASURE STRESS ALONG TENSILE SURFACE

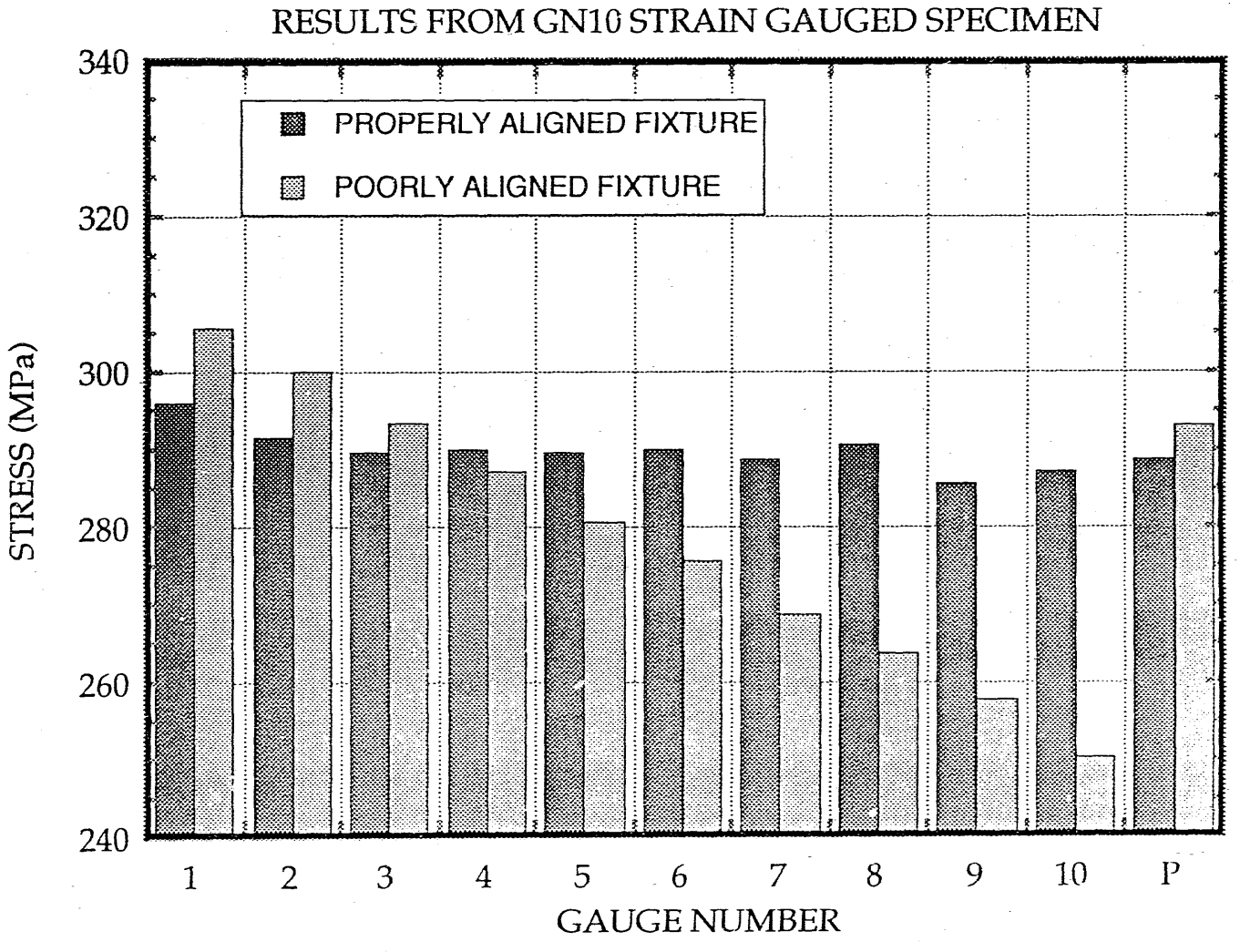
SILICON NITRIDE
FLEXURE SPECIMEN



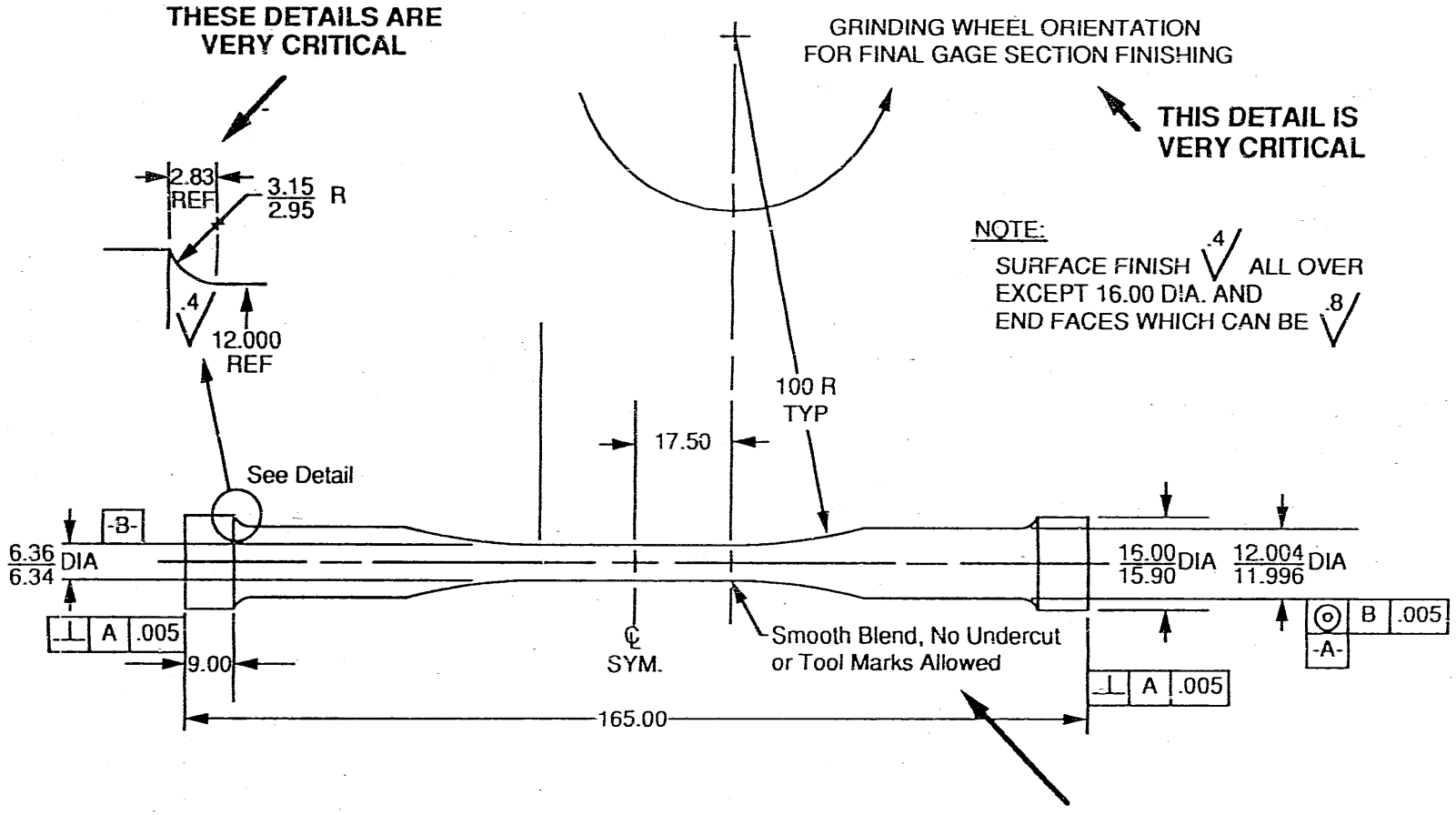
FLEXURE SPECIMEN IN FIXTURE WITH STRAIN GAGES APPLIED ON TENSILE SURFACE



PRELIMINARY STRAIN GAUGED TESTS REVEALED PROBLEMS WITH ROOM TEMPERATURE FIXTURE ALIGNMENT



TENSILE TESTING PHASE OF SUBTASK 5 IN THE UNITED STATES WILL UTILIZE BUTTONHEAD SPECIMEN

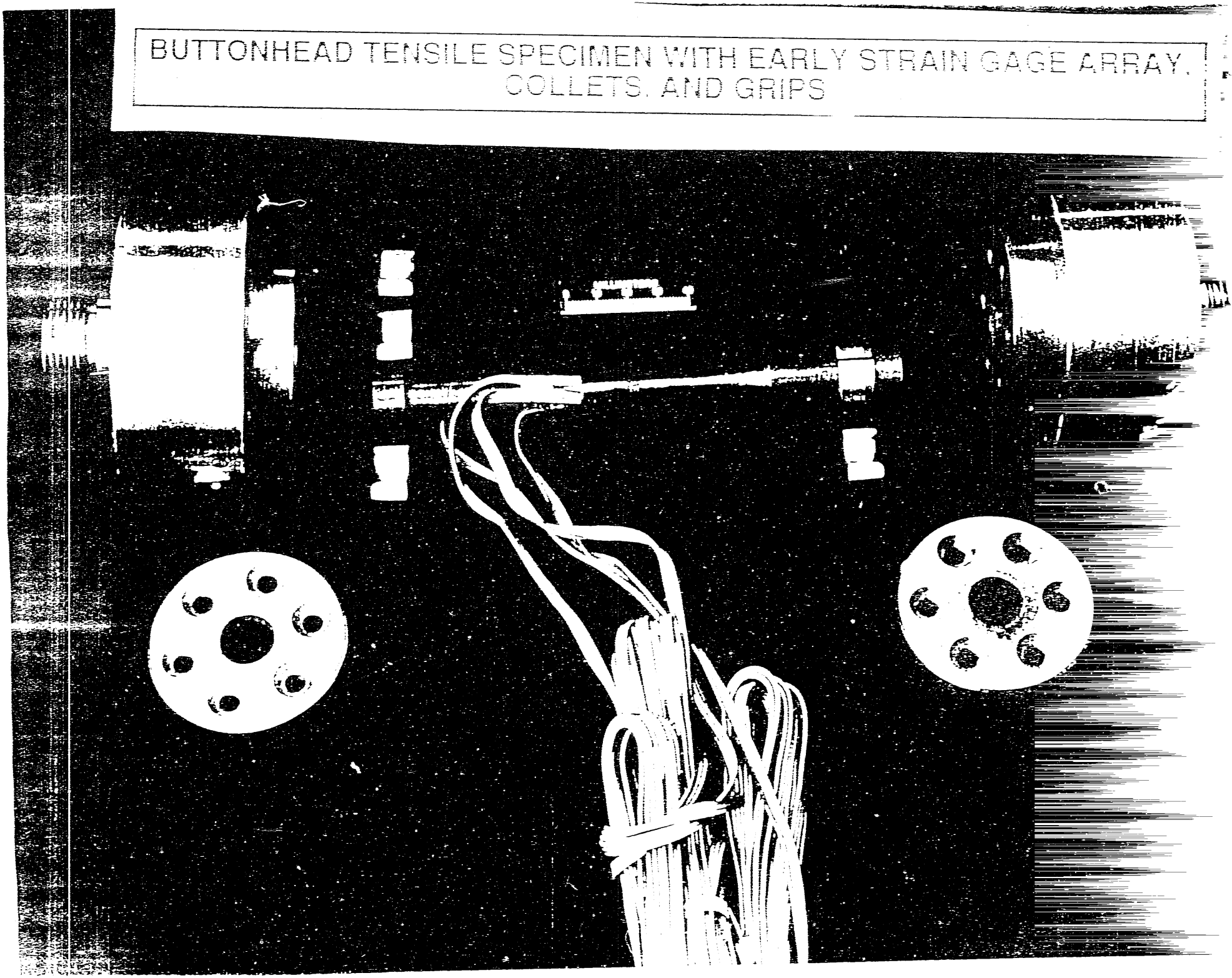


ORNL Tensile Specimen

VJT/ORNL/USA
8/2/90

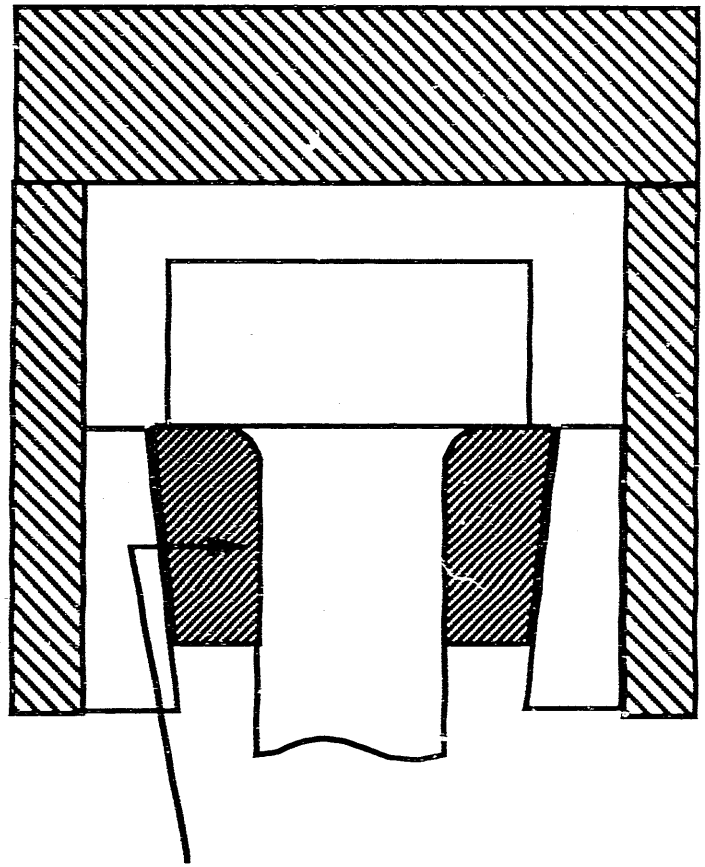
DIMENSIONS IN mm
XX DEC. +/- .25
SURF. FINISH IN MICROMETERS

BUTTONHEAD TENSILE SPECIMEN WITH EARLY STRAIN GAGE ARRAY, COLLETS, AND GRIPS



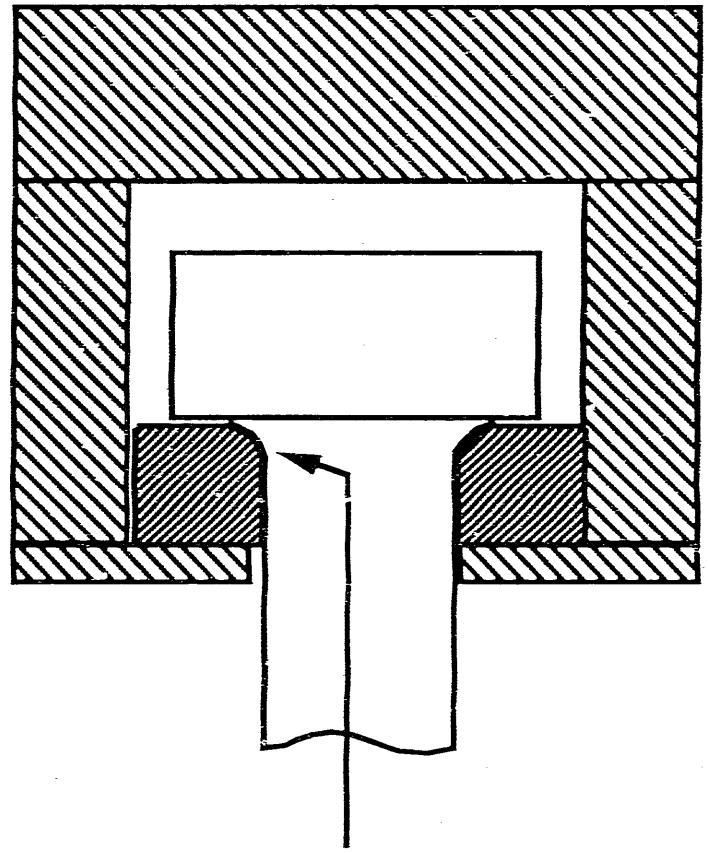
TWO TENSILE GRIP DESIGNS WILL BE EVALUATED IN SUBTASK 5

TAPERED COLLET



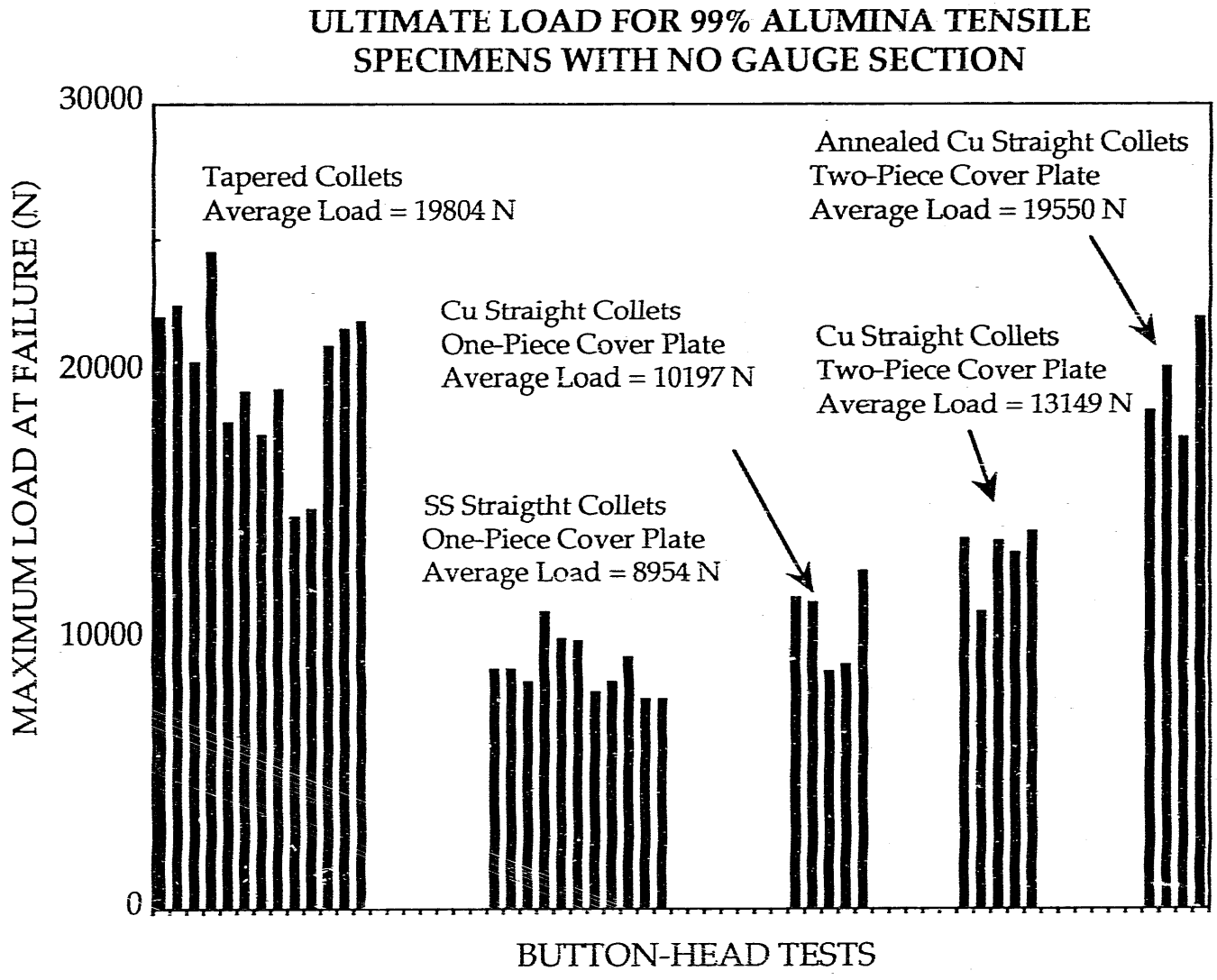
COMPRESSIVE STRESSES GENERATED WITHIN SHANK REGION

STRAIGHT COLLET DESIGN



POTENTIAL FAILURE SITE

LOADING CAPABILITY OF STRAIGHT COLLET GRIPS IS DEPENDENT UPON EXACT GRIP CONFIGURATION



MILESTONES FOR SUBTASK 5 U.S. EFFORT

- INITIATE U.S. CERAMIC SPECIMEN PROCUREMENT
  – COMPLETED 2/1/1989
- COMPLETE STRAIN GAGE SYSTEM DESIGN
  – COMPLETED 6/30/1989
- INITIATE STRAIN GAGE FLEXURE STRENGTH MEASUREMENTS
  – COMPLETED 4/30/90
- COMPLETE FLEXURE STRENGTH MEASUREMENTS
  – DUE 1/31/91
- COMPLETE TENSILE STRENGTH MEASUREMENTS IN U.S. LABORATORIES
  – DUE 9/30/91
- COMPLETE DATA ANALYSIS
  – DUE 12/31/91

-END-

DATE FILMED

11/05/90